Polarforschung 80 (2), 88 – 99, 2011

Fossil Sites in the Continental Victoria and Ferrar Groups (Triassic–Jurassic) of North Victoria Land, Antarctica

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Abstract: In contrast to the adjacent parts of the Transantarctic Mountains, the Mesozoic macrofossil record of north Victoria Land remains poorly documented. During the Ninth German Antarctic North Victoria Land Expedition (GANOVEX IX 2005/2006) twelve fossil sites in southern north Victoria Land were discovered and sampled. Fossils from the Triassic to Early Jurassic Section Peak Formation were collected from Archambault Ridge, Anderton Glacier, Skinner Ridge, Timber Peak, Vulcan Hills, Runaway Hills, Section Peak and Shafer Peak. These localities have yielded abundant fossil wood and compressions of horsetails, ferns, and seed ferns. In addition, several beetle elytra were found at Timber Peak. Fossil localities of the overlying Shafer Peak Formation and Exposure Hill-type deposits occur at Shafer Peak and in the Mount Carson area, and have yielded various trace fossils, permineralized wood, leaf compressions, and conchostracans. Two newly discovered fossil sites are associated with the late Early Jurassic Kirkpatrick lava flows. Upright-standing tree trunks have been recorded at Suture Bench, and highly fossiliferous sedimentary interbeds occur at the southwestern end of the Mesa Range. Of special interest is the exquisite fossil preservation at some of the sites. Compression fossils from Timber Peak and Shafer Peak contain well-preserved cuticles, which is very rare in the Antarctic. An Early Jurassic permineralized deposit at Mount Carson contains structurally preserved ferns. Furthermore, the arthropod fossils from sedimentary interbeds at the Mesa Range are preserved in minute detail, including antennae and limb spines of a blattid insect.

Zusammenfassung: Im Gegensatz zu benachbarten Gegenden des Transantarktischen Gebirges sind aus den triassischen und jurassischen Sedimenten Nordviktorialands bisher nur äußerst spärliche Fossilvorkommen bekannt geworden. Im Rahmen der Geländearbeiten während der 9. German Antarctic North Victoria Land Expedition (GANOVEX IX 2005/2006) wurde ein Dutzend neue Fossilfundstellen entdeckt und beprobt. Innerhalb der triassisch-frühjurassischen Section Peak Formation wurden Fossilien am Archambault Ridge, Anderton Glacier, Skinner Ridge, Timber Peak, Vulcan Hills, Runaway Hills, Section Peak und Shafer Peak entdeckt. Diese Fundstellen haben zahlreiches fossiles Holz und zum Teil sehr gut erhaltene Pflanzenfossilien, vor allem Schachtelhalme, Farne und Samenfarne, geliefert. Am Timber Peak wurden weiterhin einige Käferflügeldecken entdeckt. Fossilfundstellen der überlagernden Shafer Peak Formation und lokal eingeschalteten, mafischen vulkanoklastischen Ablagerungen (Exposure Hill-type deposits) befinden sich am Shafer Peak und in der Umgebung des Mount Carson, deren frühjurassische Sedimente verschiedene Spurenfossilien, verkieseltes Holz, Pflanzenreste und Conchostraken enthalten. Darüber hinaus wurden zwei weitere Fossilfundstellen in der Abfolge der frühjurassischen Kirkpatrick-Lavaströme entdeckt. An der Suture Bench wurden Baumstämme von den Laven umschlossen und aufrecht stehend überliefert. Äußerst fossilreiche sedimentäre Einschaltungen zwischen einzelnen Lavaströmen befinden sich am Südwestende der Mesa Range. Besonders bemerkenswert ist die zum Teil hervorragende Fossilerhaltung an einigen Fundstellen. Die Pflanzenfossilien vom Timber Peak und Shafer Peak liefern noch sehr gut erhaltene Kutikulen, was insbesondere in der Antarktis überaus selten ist. Ein verkieselter Horizont am Mount Carson enthält zahlreiche jurassische Farne in zellulärer Erhaltung. Darüber hinaus sind einige der Arthropodenfossilien aus den sedimentären Zwischenlagen der Kirkpatrick-Laven zum Teil bis in feinste Details überliefert.

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Manuscript received 10 October 2010, accepted in revised form 16 December 2010.

INTRODUCTION

The Triassic to Jurassic sedimentary record of the Transantarctic Mountains (Victoria and Ferrar groups) has yielded rich and diverse fossil assemblages. Vertebrate faunas are known from the Triassic Fremouw and Early Jurassic Hanson formations of the central Transantarctic Mountains (COLBERT & KITCHING 1975, 1977, HAMMER 1990, HAMMER et al. 1998, SMITH et al. 2007, SIDOR et al. 2008). Lacustrine interbeds associated with the Jurassic Kirkpatrick lava flows have yielded articulated skeletons of actinopterygian fishes (SCHAEFFER 1972) and abundant aquatic and terrestrial invertebrates, including gastropods, conchostracans, triopsids, ostracods, syncarids, isopods, and insects (CARPENTER 1969, BALL et al. 1979, TASCH 1987, SHEN 1994). The anatomically preserved floras from permineralized peat deposits from Fremouw Peak constitute a unique source of information on the palaeobiology and -ecology of polar ecosystems during the Triassic greenhouse world. Together with the coeval compression assemblages, they represent a diverse flora that is composed of sphenophytes, various groups of ferns, seed ferns, cycads, and conifers (TAYLOR & TAYLOR 1990). Even very delicate structures such as mycorrhizal fungi have been reported (Phipps & Taylor 1996). Jurassic plant fossils, including liverworts, ferns, cycadophytes and conifers, are known from Carapace Nunatak in south Victoria Land and Storm Peak in the central Transantarctic Mountains (PLUMSTEAD 1962, TOWNROW 1967, YAO et al. 1991, see CANTRILL & HUNTER, 2005).

Virtually all of the above-mentioned fossil assemblages come from localities in the central Transantarctic Mountains and south Victoria Land. In contrast, palaeontological data from north Victoria Land have remained sparse. Occurrences of petrified wood are common in the Priestley Glacier area, Eisenhower Range, and Mesa Range (GAIR et al. 1965, NATHAN & SCHULTE 1968, SKINNER & RICKER 1968, JEFFERSON et al. 1983). Aquatic arthropods and isolated fish scales have been described from strata underlying the Kirkpatrick lava flows at Agate Peak (NATHAN & SCHULTE 1968, TASCH 1987). The only Triassic macroflora known previously from North Victoria Land is a poorly preserved *Dicroidium* assemblage from Vulcan Hills (TESSENSOHN & MÄDLER 1987).

Field studies of the sedimentary succession in southern north Victoria Land during the Ninth German Antarctic North Victoria Land Expedition (GANOVEX IX 2005/2006) resulted in the discovery of a dozen new Triassic and Early Jurassic macrofossil sites (Fig. 1) containing well-preserved fossil assemblages of plants, invertebrates and trace fossils (Tab. 1).

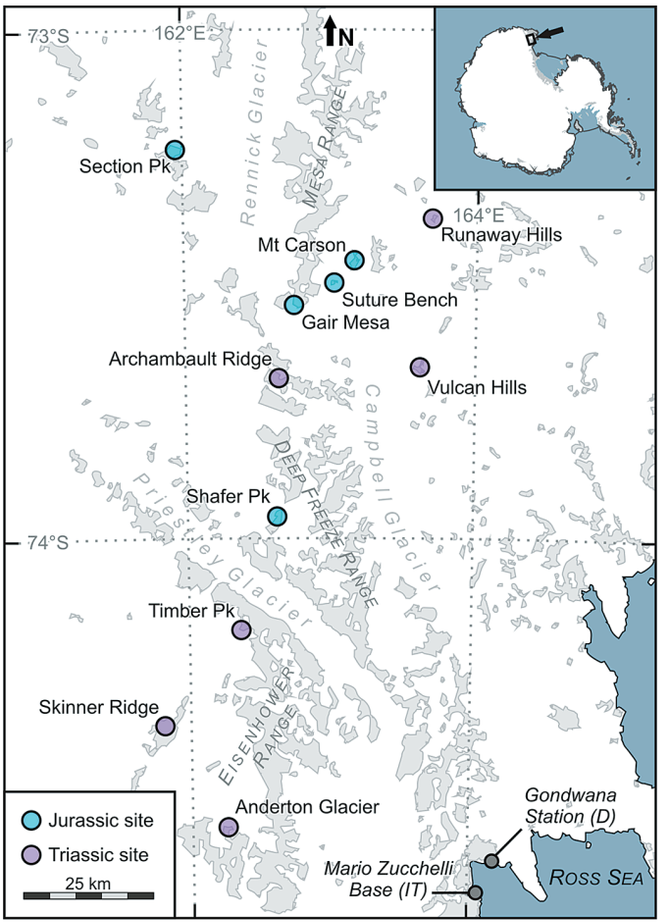

Fig. 1: Map showing the position of the newly discovered fossil sites in southern north Victoria Land.

Abb. 1: Vereinfachte topographische Karte des südlichen Nordviktorialands mit den neuen Fossilfundstellen.

GEOLOGICAL SETTING

In southern north Victoria Land, a terrestrial sedimentary sequence of c. 250-300 m thickness is intercalated between the Palaeozoic crystalline basement and the late Early Jurassic Kirkpatrick Lava Flows. It is the shortest sequence of Mesozoic sediments in the Transantarctic Mountains, both in terms of thickness and time span (see COLLINSON 1990). Jurassic sill intrusions (Ferrar Dolerite suite) with a total thickness of up to 700 m occur within this sedimentary sequence. Prior to GANOVEX IX, two sedimentary units were recognized: the Section Peak Formation and the supposedly overlying Exposure Hill Formation (COLLINSON et al. 1986, ELLIOT et al. 1986). Field investigations during GANOVEX IX resulted in a revision of the stratigraphy, which now includes two distinct sedimentary units (Section Peak and Shafer Peak formations) and a suite of intercalated mafic hydrovolcanic deposits (Exposure Hill-type deposits) (SCHÖNER et al. 2007, VIERECK-GOETTE et al. 2007) (Fig. 2).

The Section Peak Formation (thickness c. 200 m) is mainly exposed along the edge of the Polar Plateau, i.e. in the Eisenhower and Deep Freeze ranges, and from Archambault Ridge along the Vantage, Lichen and Sequence hills to Roberts Butte (SCHÖNER et al. 2011 this vol.). Isolated exposures of the Section Peak Formation are found east of the Rennick Glacier, at Vulcan and Chisholm hills, Stewart Heights and Runaway Hills (SCHÖNER et al. 2011 this vol.). The unit mainly consists of medium- to coarse-grained fluvial sandstones with minor intercalations of conglomeratic layers and fossiliferous carbonaceous shales (COLLINSON et al. 1986, TESSENSOHN & MÄDLER 1987, SCHÖNER et al. 2011 this vol.). Several pelitic intercalations in the upper part of the formation, including fossiliferous mudstone and coal, are exposed in the Priestley Glacier area. Lithologically similar, fine-grained units also occur at isolated outcrops at Section Peak, Vulcan Hills and

Locality	Horizon	Unit*	Fossil content
Gair Mesa (EH)	EH16	KLF	trace fossils, conchostracans, ostracods, insects, plant impressions (*Otozamites*)
Suture Bench (SB)	SB	KLF	silicified wood, *in situ* trunks
Mount Carson E (CE)	CEp	EHT_2	plant compressions (*Otozamites*, ?*Zamites*)
	CE13	SHF	plant detritus and leaf fragments
	CEL12	EHT_1	conchostracans
	CEL11	EHT_1	silicified plants (mainly ferns)
Mount Carson N (CN)	CN14	SHF	conchostracans, beetle elytra, plant fragments
	CN08	SHF	plant compressions (*Equisetum*)
	CN04	SHF	trace fossils (*Diplichnites*, *Scoyenia*, root traces)
Mount Carson SW (CWS)	CWS02	SHF	coalified wood, partly silicified, *in situ* trunks
Shafer Peak (SH)	SHC32	SHF	plant compressions, partly with cuticles (*Otozamites*, ferns, conifers)
	SHB07	EHT_1	conchostracans
	SHA13	SPF	beetle elytra, plant compressions (*Equisetum*)
	SPL-H	SPF	plant compressions (*Cladophlebis*)
Section Peak (SP)	SPP30b	SPF	wood and plant detritus, dispersed cuticles
Runaway Hills (RH)	RH01	SPF	plant detritus and leaf impressions (*Taeniopteris*)
Vulcan Hills (VH)	VH09	SPF	plant compressions (*Dicroidium*, *Heidiphyllum*, *Linguifolium*, *Dejerseya*)
Timber Peak (TI)	TI13	SPF	plant compressions, partly with cuticles (*Dicroidium*, *Litothallus*)
	TI12	SPF	beetle elytra, leaf fragments (*Heidiphyllum*, *Cladophlebis*)
	TI01	SPF	wood and peat rafts, silicified
Skinner Ridge (SR)	SR	SPF	wood and plant detritus, partly silicified
Anderton Glacier (AG)	AG04	SPF	plant detritus
Archambault Plateau North (AN)	AN01–02	SPF	haematitic/limonitic wood and peat rafts

Tab. 1: Stratigraphic occurrence and fossil content of fossiliferous horizons in southern north Victoria Land (see also Figs. 1 and 2). * KLF = Kirkpatrick lavas or sedimentary interbeds, EHT = Exposure Hill-type deposits, SHF = Shafer Peak Fm., SPF = Section Peak Fm.

Tab. 1: Stratigraphisches Auftreten und Zusammensetzung der fossilführenden Schichten im südlichen Nordviktorialand (siehe Abb. 1 und 2). * KLF = Kirkpatrick Laven bzw. sedimentäre Einschaltungen, EHT = Exposure Hill entsprechende Ablagerungen, SHF = Shafer Peak Formation, SPF = Section Peak Formation.

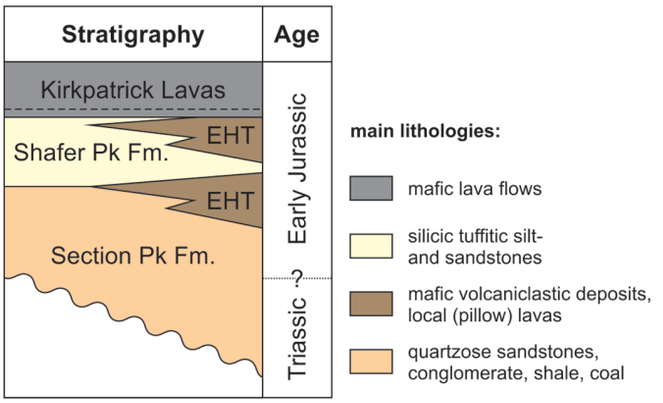

Fig. 2: Simplified chart showing the stratigraphic relationships, ages, and main lithologies of the Mesozoic rock units in southern north Victoria Land (after SCHÖNER et al. 2007, 2011 this vol.).

Abb. 2: Vereinfachte Darstellung der stratigraphischen Zusammenhänge, Alter und Hauptlithologien der mesozoischen Gesteinseinheiten im südlichen Nordviktorialand (nach SCHÖNER et al. 2007, 2011 dieses Heft).

Runaway Hills. The exact age of the Section Peak Formation remains unresolved. Palynological samples from Timber Peak and Section Peak are suggestive of a Middle Triassic to Early Jurassic age (GAIR et al. 1965, NORRIS 1965). A subsequent report of the typically Middle to Late Triassic Gondwanan seed fern *Dicroidium odontopteroides* from Vulcan Hills, however, supports a Triassic age for the Section Peak Formation (TESSENSOHN & MÄDLER 1987). An isolated piece of fossil wood from slope debris at Skinner Ridge would, according to CASNEDI & DI GIULIO (1999), indicate a post-Carnian age. Palynological reinvestigations of the Section Peak locality confirm an Early Jurassic age for the uppermost part of the formation (PERTUSATI et al. 2006). The lower and middle parts of the Section Peak Formation likely correspond to the Upper Lashly Formation of south Victoria Land and the Falla Formation of the central Transantarctic Mountains (SCHÖNER et al. 2011 this vol.).

The Section Peak Formation is conformably overlain by the Shafer Peak Formation (maximum thickness c. 50 m (SCHÖNER et al. 2007). This unit consists of predominantly ripple cross-laminated, tuffaceous, light grey silt- to fine-grained sandstone with up to 1 m thick intercalations of greenish mudstones. Complete or nearly complete sequences of the Shafer Peak Formation are found in the Deep Freeze Range (Shafer Peak, Mount Adamson) and the Mount Carson area. The Shafer Peak Formation has been interpreted as a regional equivalent of the upper part of the Hanson Formation (ELLIOT 1996) of the central Transantarctic Mountains (SCHÖNER et al. 2007). Isolated rock rafts with comparable lithologies occur in mafic volcanic breccias in south Victoria Land (ELLIOT et al. 1986).

First intrusions of Ferrar Dolerite sills during the Early Jurassic resulted in a variety of water-magma interactions (VIERECK-GOETTE et al. 2007) ranging from the formation of small-scale peperitic intrusions to large hydrovolcanic eruption centres that produced the mafic volcaniclastic breccias (ELLIOT et al. 1986). These are now recognized as multiple asynchronous deposits occurring locally near the base and top of the Shafer Peak Formation. VIERECK-GOETTE et al. (2007) therefore propose to refer to these deposits as Exposure Hill-type deposits instead of describing them as a stratigraphic formation as suggested by ELLIOT et al. (1986). The deposits occur either as massive, coarse-grained tuff breccias cross-cutting the epiclastic sequence, or as conformable intercalations of fine- to coarse-grained mafic volcaniclastics near the base or the top of the Shafer Peak Formation.

FOSSIL SITES

Archambault Ridge (73° 41' S, 162° 45' E) and Archambault N' Plateau (73° 41' S, 162° 36' E), Section Peak Formation

Easily accessible exposures of the basal section of the Section Peak Formation at Archambault Ridge have first been described by DI GIULIO et al. (1997). Sediments are exposed along the steep cliffs of the Polar Plateau escarpment in the west as well as on the eastward-extending Archambault Ridge. In the western outcrop (Archambault N' Plateau), the weathered granitic basement forms a prominent plateau, and is erosively overlain by c. 65 m of sediments of the Section Peak Formation followed by a dolerite sill. The basal 2-3 m of the sequence are composed of coarse-grained, pebbly, trough-cross-bedded channel sandstones and conglomerates (Fig. 3a). Channel lag deposits contain abundant tree trunks up to 15 cm wide and 40 cm long (Fig. 3b). The wood substance is replaced by haematite/limonite, and usually shows conspicuous growth rings. In addition, internally structure-less, rounded haematitic clasts up to 30 x 10 cm large occur (Fig. 3b). These clasts are interpreted as rafts of permineralized peat, indicating erosion and redeposition of backswamp deposits.

Anderton Glacier (74° 35' S, 162° 17' E), Section Peak Formation

About 70 m of braided-river type conglomerates of the basal Section Peak Formation are exposed on a gentle slope in the Anderton Glacier area. Fine-clastic interbeds are predominant in the middle to upper half of the section. These interbeds form lenticular bodies 0.3-1.2 m thick that consist of planar non-parallel to wavy bedded, grey to black, fine-sandy siltstone to silty sandstone interpreted as channel plugs. In these fine-grained successions rectangular fragments of narrow coalified plant axes (<2 cm in diameter) are common. A single, indeterminable leaf fragment was found.

Skinner Ridge (74° 21' S, 161° 51' E), Section Peak Formation

The Skinner Ridge locality has only been visited briefly and sampled during a reconnaissance flight. Approximately 25-35 m of mainly medium-grained sandstones of the Section Peak Formation are exposed between two Ferrar sills. Upright tree trunks up to 30 cm in diameter are common in several levels. Higher up in the section, a 40 cm thick channel fill of greyish-black siltstone with flattened trunks up to 25 cm wide is exposed. A particularly well-preserved fossil tree trunk at Skinner Ridge has been declared an "Antarctic Geological Monument" by the PNRA, Italia (Fig. 3c).

Many channel sandstones contain plant detritus and small

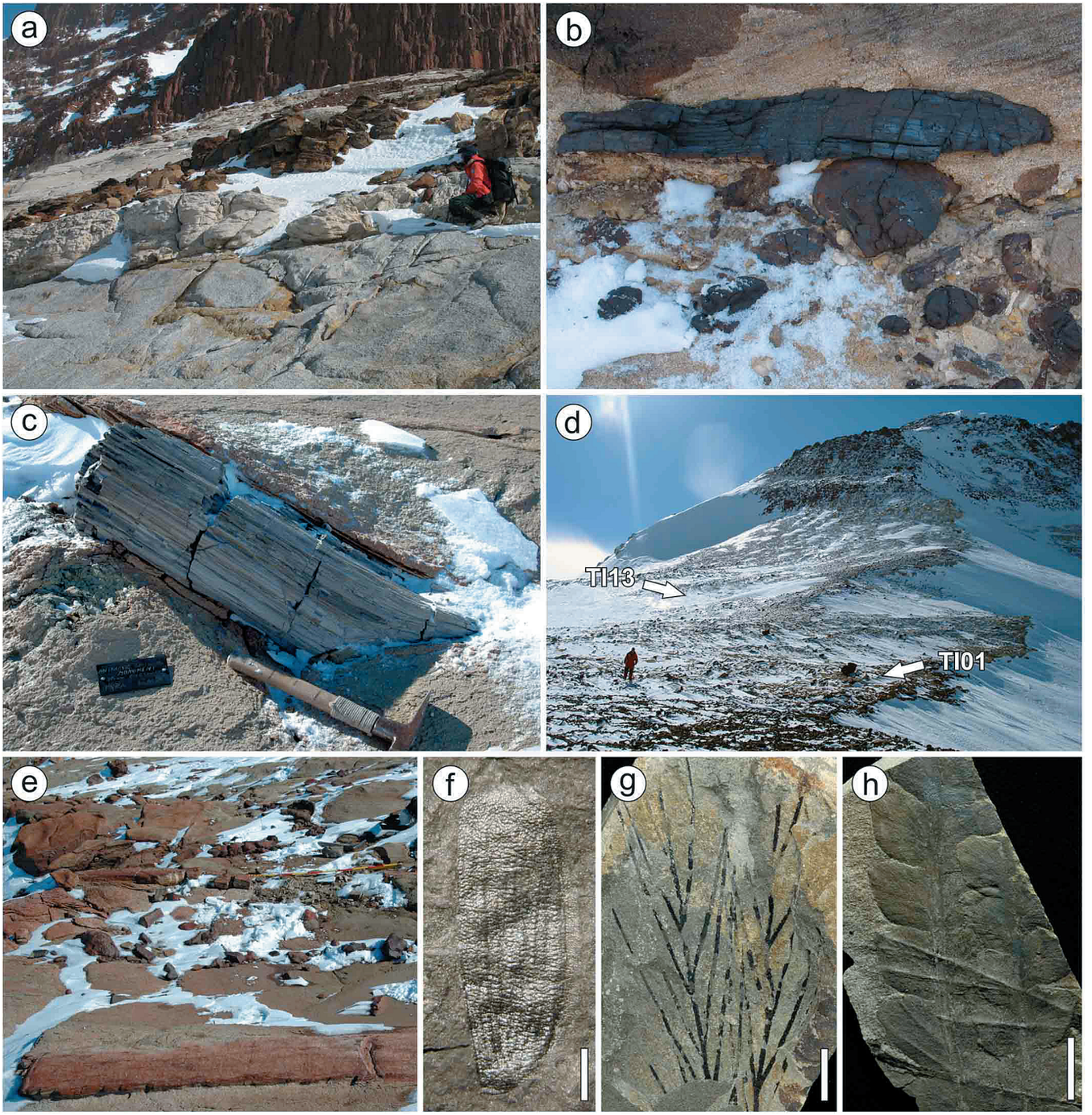

Fig. 3: Triassic fossil sites of the Section Peak Formation, southern north Victoria Land. (a) = base of the Section Peak Formation at the western slope of Archambault Plateau North. The conglomeratic channel lag deposits contain abundant fossil wood. (b) = haematitic wood and clasts at Archambault Ridge. (c) = large permineralized trunk declared as "Antarctic Geological Monument" by the PNRA, Italia, at Skinner Ridge in the basal to middle part of the Section Peak Formation. (d) = exposure of the upper part of the Section Peak Formation intercalated between two sills at Timber Peak, Eisenhower Range. Abundant permineralized tree stems and blocks of silicified peat occur scattered over the extensively exposed bedding planes at the base of the profile (TI01). Fine-grained intercalations including fossiliferous mudstones (TI12 and TI13) and coal are indicated by steeper slope morphology and snow cover. (e) = up to 3 m large silicified stems at the base of the Timber Peak outcrop, Upper Triassic. (f) = beetle elytron, Timber Peak, Upper Triassic. Scale bar: 1 mm. (g) = seed fern frond *Dicroidium elongatum,* Timber Peak, Upper Triassic. Scale bar: 1 cm. (h) = seed fern frond *Dicroidium odontopteroides,* Timber Peak, Upper Triassic. Scale bar: 1 cm.

Abb. 3: Triassische Fossilfundstellen der Section Peak Formation, südliches Nordviktorialand. (a) = Basis der Section Peak Formation am Archambault Plateau Nord. Die konglomeratischen Rinnenfüllungen enthalten zahlreiches fossiles Holz. (b) = Holz und Hämatitklasten am Archambault Plateau Nord, Trias. Scale bar: 100 μm. (c) = großer verkieselter Stamm innerhalb der basalen bis mittleren Section Peak Formation, der von der italienischen PNRA als „Antarctic Geological Monument" gekennzeichnet ist; Skinner Ridge, Trias. (d) = Von zwei Lagergängen begrenzter Aufschluss des oberen Teils der Section Peak Formation am Timber Peak, Eisenhower Range. Zahlreiche verkieselte Baumstämme und Lesesteine eines verkieselten Torfhorizontes liegen verstreut auf den Schichtflächen an der Basis der Abfolge (TI01). Feinkörnige Einschaltungen von fossilführenden Silt- und Tonsteinen (TI12 und TI13) sowie Kohle sind in den steileren Hangbereichen unter Schnee und Hangschutt verborgen. (e) = bis zu 3 m lange, verkieselte Baumstämme an der Basis des Timber Peak Profils, Obertrias. (f) = Flügeldecke eines Käfers, Timber Peak, Obertrias. Maßstab 1 mm. (g) = Samenfarn *Dicroidium elongatum,* Timber Peak, Obertrias. Maßstab: 1 cm. (h) = Samenfarn *Dicroidium odontopteroides,* Timber Peak, Obertrias. Maßstab: 1 cm.

pieces of fossil wood. Others are particularly rich in intraclasts, including rounded, pale-grey siltstone pebbles and up to 10 cm thick and 50 cm long rafts of partly silicified carbonaceous shale with coal layers. Some of the channel fills are finely rooted.

Timber Peak (74° 11' S, 162° 23' E), Section Peak Formation

At Timber Peak, c. 80 m of the Section Peak Formation are intercalated between two Ferrar sills (Fig. 3d). The sequence consists of alternating medium- to coarse-grained sandstone and fine-grained sediments including coal seams. The locality was first mentioned by RICKER (1964), who reported fossil tree stems, including in situ trunks, from the basal part of the section. Subsequent palynological analyses of the fine-grained intercalations in the section indicated a Middle to Late Triassic age (GAIR et al. 1965, NORRIS 1965). In a review of the Beacon microfloras from the Transantarctic Mountains, KYLE (1977) placed the Timber Peak microflora in subzone C or D of the Late Triassic *Alisporites*-Zone.

Abundant silicified logs and loose blocks of silicified peat about 10 cm thick occur scattered throughout the exposed bedding planes at the base of the section (TI01; Fig. 3e). Trunks are commonly E–W oriented, up to 3 m long (not fully exposed/preserved), 10 cm to 30 cm wide, and strongly compressed. A large specimen (~60 cm in diameter) probably represents an overturned tree stump. The 15 m thick fine-grained unit overlying the basal sandstones was studied in detail. Macrofossils were found in carbonaceous silt- and claystone layers below (TI12) and above (TI13) a c. 1 m thick coal seam. The associations below the coal seam comprise fragments of the foliage morphotaxa *Heidiphyllum* (Coniferales) and *Cladophlebis* (Filicales), as well as numerous isolated seeds and several elytra of reticulated beetles (Fig. 3f). The flora above the seam is dominated by fronds and frond fragments of the seed fern *Dicroidium*, with *D. elongatum* (Fig. 3g) and *D. odontopteroides* (Fig. 3h) being the most common species. The *Dicroidium* flora from Timber Peak has yielded exquisitely cuticles (Fig. 4a, 4b). The putative freshwater alga *Litothallus ganovex* has been described based on compressions and cellular sheets from Timber Peak (BOMFLEUR et al. 2009).

Vulcan Hills (73° 40' S, 163° 37' E), Section Peak Formation

The locality was described by TESSENSOHN & MÄDLER (1987) and revisited during GANOVEX IX. At the southeastern ridge of Vulcan Hills, a c. 180 m thick sedimentary sequence of the Section Peak Formation is exposed in a cliff facing towards the south (Fig. 4c). The sequence directly overlies the crystalline basement and is capped by a Ferrar Dolerite sill. The uppermost 30 m of the sequence were documented along the WNW-ESE-oriented ridge. This section consists of light-grey, fine- to medium-grained quartzose sandstone. Abundant plant fossils occur in a 1 m thick black-shale intercalation (VH09) c. 13 m below the sill (Fig. 4c). A volcanic dyke apparently intruded the fossiliferous horizon and locally formed intrusive pyroclastic breccias. As a result, the fossils are thermally altered and consist of silvery compressions with a conspicuous metallic lustre; cuticles are not preserved. TESSENSOHN & MÄDLER (1987) have described *Dicroidium odontopteroides* (Fig. 4d), *Linguifolium* (Fig. 4e), *Neocalamites,* and an unidentified seed from this exposure. The newly collected material includes abundant leaves of *Heidiphyllum elongatum* (Fig. 4f) and fragments of *Dejerseya* sp. (Fig. 4g).

Runaway Hills East (73° 25' S, 163° 55' E), Section Peak Formation

Fossiliferous siltstones (RH; Fig. 4h) were found in slope debris among loose blocks of medium- to coarse-grained quartzose sandstone, Ferrar Dolerite sill, and hyaloclastic breccia. The slope morphology and distribution of loose sediment blocks might indicate that the interval covered by snow and slope debris consists of an alternation of sandstone and mudstone. Several blocks of medium-grey siltstone contain plant fossils, including impressions of large, up to 4 cm wide *Taeniopteris*-like leaves (Fig. 4i). Other blocks contain abundant defoliated axes and plant roots.

Section Peak (73° 14' S, 161° 55' E), Section Peak Formation

The sedimentary sequence exposed at Section Peak rests on the crystalline basement and is intersected by a thick Ferrar sill. The succession was first described by GAIR et al. (1965), who regarded the mafic igneous rocks as lava flows of the Kirkpatrick Basalts. COLLINSON et al. (1986) reinterpreted this succession and designated it as the type section of the Section Peak Formation. Palynological associations from fine-grained layers in the upper part of the sequence were studied by GAIR et al. (1965) and NORRIS (1965). The samples were dated as Middle or Late Triassic to Early Jurassic. Recent analyses of newly recovered samples confirm NORRIS' assignment to the Early Jurassic (PERTUSATI et al. 2006).

Macrofossils were discovered from a new site on the uppermost plateau of the Section Peak outcrop (Fig. 4j), c. 250 m W' of the outcrop illustrated by PERTUSATI et al. (2006, Fig. 3). Field observations indicate that this sequence covers the base of the upper part of the Section Peak outcrop, which has been displaced by a non-stratiform Ferrar Dolerite sill and is therefore missing in the eastern part of the plateau. It consists of at least 4 m of dark-grey, mica-rich, barren mudstones. These are erosively overlain by intraclast-rich conglomeratic and coarse-grained sandstone layers, which in turn are overlain by medium- to coarse-grained quartzose sandstones forming the upper part of the unit (see SCHÖNER et al. 2011 this vol.). Macrofossils were found in a single, light-grey intraclast with a diameter of 40 cm (SPL-H), retrieved from an intraclast-rich conglomeratic layer above the mudstone unit (Fig. 4j). Plant remains comprise well-preserved frond portions of *Cladophlebis* (Figs. 4k, 4l), a morphogenus for sterile fern foliage. Other intraclasts are rich in plant roots. Fragmented plant cuticles have been isolated from carbonaceous siltstone interbeds (SPP30b) from the upper part of the outcrop.

Shafer Peak (74° 00' S, 162° 36' E), Section Peak and Shafer Peak formations, Exposure Hill-type deposits

MUSUMECI et al. (2006) provided a first, simplified overview

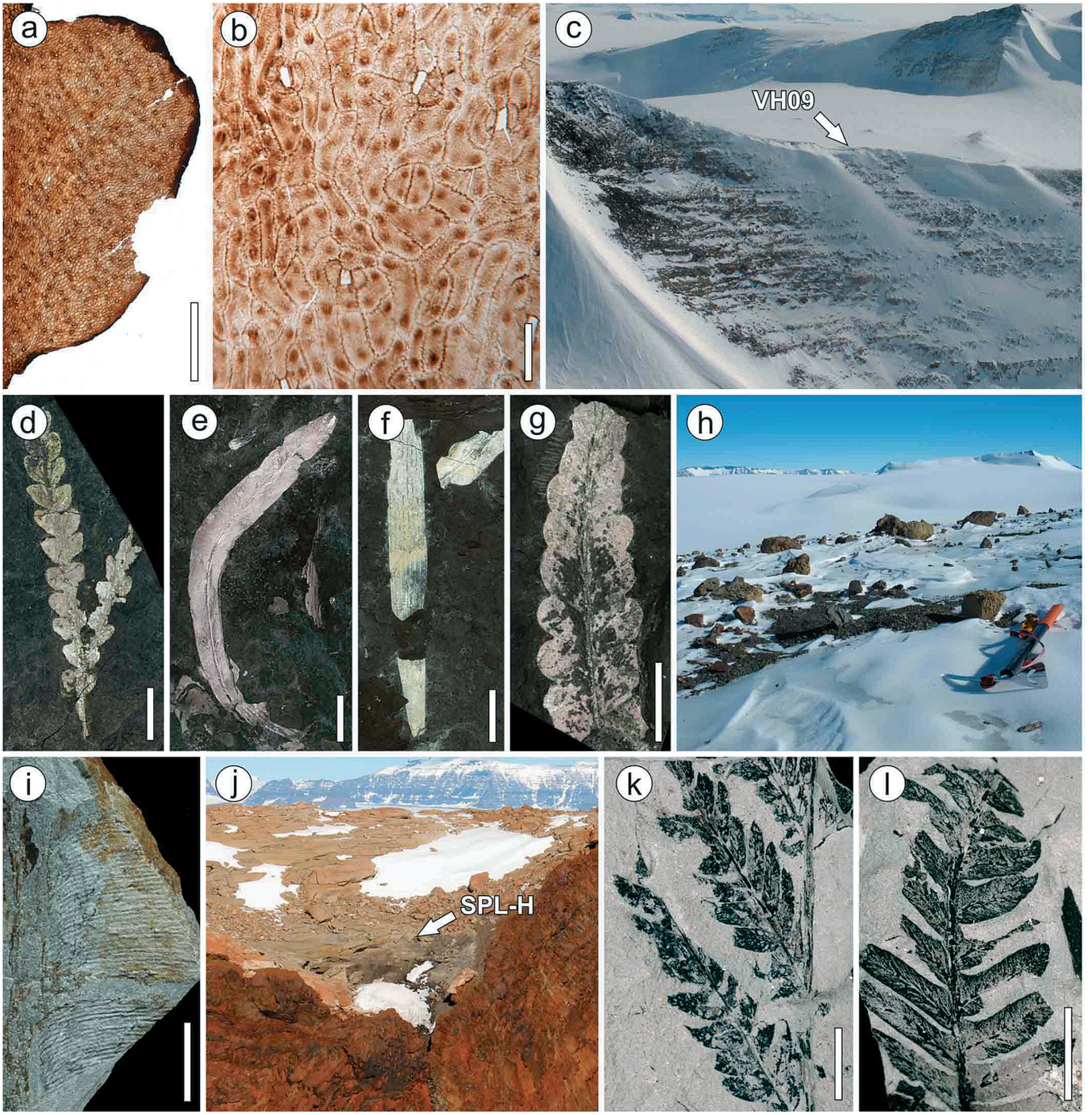

Fig. 4: Triassic to Early Jurassic fossil sites of the Section Peak Formation, southern north Victoria Land. (a) = cuticle of a complete pinnule of *Dicroidium odontopteroides;* Timber Peak, Upper Triassic. Scale bar: 1 mm. (b) = cuticle showing cell pattern, papillae, and distribution of stomata; Timber Peak, Upper Triassic. (c) = location of fossiliferous black shales (VH09) in the upper part of the Section Peak Formation at Vulcan Hills. (d) = *Dicroidium odontopteroides;* Vulcan Hills, Upper Triassic. Scale bar: 1 cm. (e) = *Linguifolium tenison-woodsii;* Vulcan Hills, Upper Triassic. Scale bar: 1 cm. (f) = *Heidiphyllum elongatum;* Vulcan Hills, Upper Triassic. Scale bar: 1 cm. (g) = *Dejerseya* sp.; Vulcan Hills, Upper Triassic. Scale bar: 1 cm. (h) = isolated exposure of plant-bearing siltstones of the upper(?) part of the Section Peak Formation in the eastern Runaway Hills. (i) = *Taeniopteris* sp.; Runaway Hills, Upper(?) Triassic. Scale bar: 1 cm. (j) = base of the upper outcrop of the Section Peak Formation at Section Peak. Arrow indicates the position of fossiliferous intraclasts (SPL-H) above dark-grey lake sediments. (k, l) = Fern foliage *Cladophlebis* sp.; Section Peak, Lower Jurassic. Scale bars: 1 cm.

Abb. 4: Triassische und frühjurassische Fossilfundstellen der Section Peak Formation, südliches Nordviktorialand. (a) = Kutikula eines kompletten Fiederchens von *Dicroidium odontopteroides,* Timber Peak, Obertrias. Maßstab: 1 mm. (b) = Kutikula mit Zellmuster, Papillen und Spaltöffnungen, Timber Peak, Obertrias. Maßstab: 100 μm. (c) = Aufschluss fossilreicher Schwarzschiefer (VH09) im oberen Teil der Section Peak Formation in den Vulcan Hills. (d) = *Dicroidium odontopteroides,* Vulcan Hills, Obertrias. Maßstab: 1 cm. (e) = *Linguifolium tenison-woodsii,* Vulcan Hills, Obertrias. Maßstab: 1 cm. (f) = *Heidiphyllum elongatum,* Vulcan Hills, Obertrias. Maßstab: 1 cm. (g) = *Dejerseya* sp., Vulcan Hills, Obertrias. Maßstab: 1 cm. (h) = isoliertes Vorkommen pflanzenführender Silt- und Tonsteine im oberen(?) Bereich der Section Peak Formation in den östlichen Runaway Hills. (i) = *Taeniopteris* sp., östliche Runaway Hills, Obere(?) Trias. Maßstab: 1 cm. (j) = basaler Bereich des oberen Aufschlusses der Section Peak Formation am Section Peak. Der Pfeil markiert die Position pflanzenführender Intraklasten (SPL-H) oberhalb von dunkelgrauen Seeablagerungen. (k, l) = Farnbeblätterung *Cladophlebis* sp., Section Peak, Unterjura. Maßstab: 1 cm.

of some lithologies of the succession exposed along the northern flank of Shafer Peak (Fig. 5a). The section was documented in detail during GANOVEX IX (see SCHÖNER et al. 2007, 2011 this vol.). It represents the most complete sedimentary sequence in southern north Victoria Land, and includes the upper part of the Section Peak Formation, the overlying Shafer Peak Formation and two intercalated sections of Exposure Hill-Type deposits, occurring at the base and top of the Shafer Peak Formation. This section was proposed as type section for the Shafer Peak Formation (SCHÖNER et al. 2007).

The upper part of the Section Peak Formation at Shafer Peak consists of an alternation of at least four cliff-forming bodies of medium- to coarse-grained sandstone with poorly exposed interbedded siltstones and dark-grey silt- and mudstones. A single bed (SHA13) within one of the fine-grained sections has yielded abundant and excellently preserved equisetalean remains and small beetle elytra. The uppermost layers of the Exposure Hill-type deposits at the base of the Shafer Peak Formation consist of lacustrine carbonaceous shale rich in conchostracan valves (SHB07). This black shale has yielded a well-preserved Early Jurassic microflora (MUSUMECI et al. 2006). Several beds within the overlying succession of volcaniclastic silt- to fine-grained sandstones of the Shafer Peak Formation are rich in intraclasts. Small intraclasts of black shale may contain conchostracans. A single bed (Fig. 5b; SHC32) contains abundant, up to 40 cm long and well-preserved plant compressions and impressions, mainly the bennettitalean leaf *Otozamites* (Fig. 5c). Several impressions of dipterid ferns (Fig. 5d), other pteridophytes, and a few conifer remains were recorded as well. The bedding planes are covered by coalified plant debris. Bulk macerations of this horizon have yielded fragmentary, but well-preserved conifer twigs (Fig. 5e) and needles (Fig. 5f). Incident UV fluorescence revealed that cuticles also are well preserved in many of the cycadophyte fronds.

Mount Carson area (around 73° 27' S, 163° 12' E), Shafer Peak Formation, Exposure Hill-type deposits

Several outcrops located on the ridges around Mount Carson have yielded plant and animal fossils from the Shafer Peak Formation and Exposure Hill-type deposits. The most complete sedimentary succession is exposed along the eastern ridge of Mount Carson (Fig. 5g). It includes an isolated occurrence of mafic volcaniclastic and lacustrine deposits (CEL) at the base of the ridge that is separated from the rest of the section by a sill intrusion. The following, continuously exposed sequence consists of at least 35 m of the Shafer Peak Formation (CE) overlain by coarse-grained volcaniclastic deposits followed by pillow lavas and lava flows. The CEL section consists of a c. 12 m thick series of fine- to medium-grained black sandstones rich in pyroclasts and up to 5 mm-sized intraclasts, overlain by 7 m of medium-grey laminated claystones (Fig. 5h). A 20 cm thick siliceous fossil-rich deposit (CEL11) occurs below these claystones. It shows graded bedding from lapilli-rich sandstone at the base to ash-bearing silt- to claystone at the top. This horizon contains abundant permineralized foliage and axes, mainly of dipterid ferns (Fig. 5i). In addition, sterile and fertile remains of an unidentified fern, a permineralized *Otozamites*-frond, ovuliferous organs, and gymnosperm wood were found. Bed CEL11 is directly overlain by a 1 cm thick, pure claystone with abundant and well-preserved conchostracan valves. The basal layers of the overlying lacustrine series have yielded highly fragmented and thus unidentifiable arthropod cuticles. Fine-grained sandstone lenses intercalated within the succession of laminated claystones are intensely bioturbated.

Plant fragments were found in an intraclast-rich layer (CE13-15) in the overlying Shafer Peak Formation. Macrofossils are generally <5 cm small, moderately preserved impressions and compressions of equisetophytes, ferns, putative seed ferns and bennettitaleans. *Scoyenia*-type burrows were occasionally observed on exposed bedding planes throughout the profile. In addition, abundant plant remains occur at the base of the lacustrine beds directly underlying the initial pillow lavas at the top of the sedimentary profile (CEp). The dark olive-grey siltstones are intensely deformed and thermally altered. The plant fossil assemblage is dominated by cycadophyte frond fragments provisionally assigned to *Otozamites* and *Zamites* (Fig. 5j).

Other fossiliferous horizons are exposed at a ridge extending northwards from Mount Carson (Fig. 6a). The section covers c. 50 m of the Shafer Peak Formation with intercalated mafic volcaniclastics (Exposure Hill-type deposits), and is capped by a dolerite sill. A single, extensively exposed bedding plane at the base of the profile (CN04) contains abundant root traces, *Scoyenia*-type burrows and *Diplichnites*-type arthropod trackways (Fig. 6b). Higher up in the profile, a bed with larger pyroclasts (CN14) has yielded an assemblage of fragmentary plant fossils (Fig. 6c), conchostracans (Fig. 6d) and a single beetle elytron (Fig. 6e).

On a spur southwest of Mount Carson, a small isolated section of the Shafer Peak Formation with interbedded mafic volcaniclastics is intercalated between two sills. Remains of an in situ-stand of at least four gymnosperm trees were found on an exposed bedding plane. The wood substance is coalified and only partially silicified (Fig. 6f). Most of the stems are eroded, leaving well-defined, nearly circular areas filled with broken wood fragments (Fig. 6g). The smallest stem has a diameter of only 5 cm and probably represents a secondary stem or branch that arises from a much thicker stem close by. The largest stem has a diameter of nearly 50 cm.

Suture Bench (73° 29' S, 163° 05' E), Kirkpatrick lavas

Most of the slope on the southeastern face of Suture Bench is covered with rock debris of Kirkpatrick lavas and tuffitic siltstone of the Shafer Peak Formation; isolated small outcrops consist of Exposure Hill-type deposits. The small, steep cliffs at the top of the outcrop are formed by pillow lavas (Fig. 6h). Silicified tree stems are buried in situ within the initial lava flows (Figs. 6i, 6j). They occur in close proximity to each other (<1 m distance apart). The largest trunk has a diameter of 23 cm (Fig. 6j); the three smallest axes, each c. 8 cm in diameter, occur together and probably represent the distal portion of a repeatedly branched stem (Fig. 6i). Pieces of silicified wood of various size (up to 25 cm diameter) are abundant in the slope debris. Some specimens show characteristic holes and tunnels less than 1 cm wide that may represent arthropod borings.

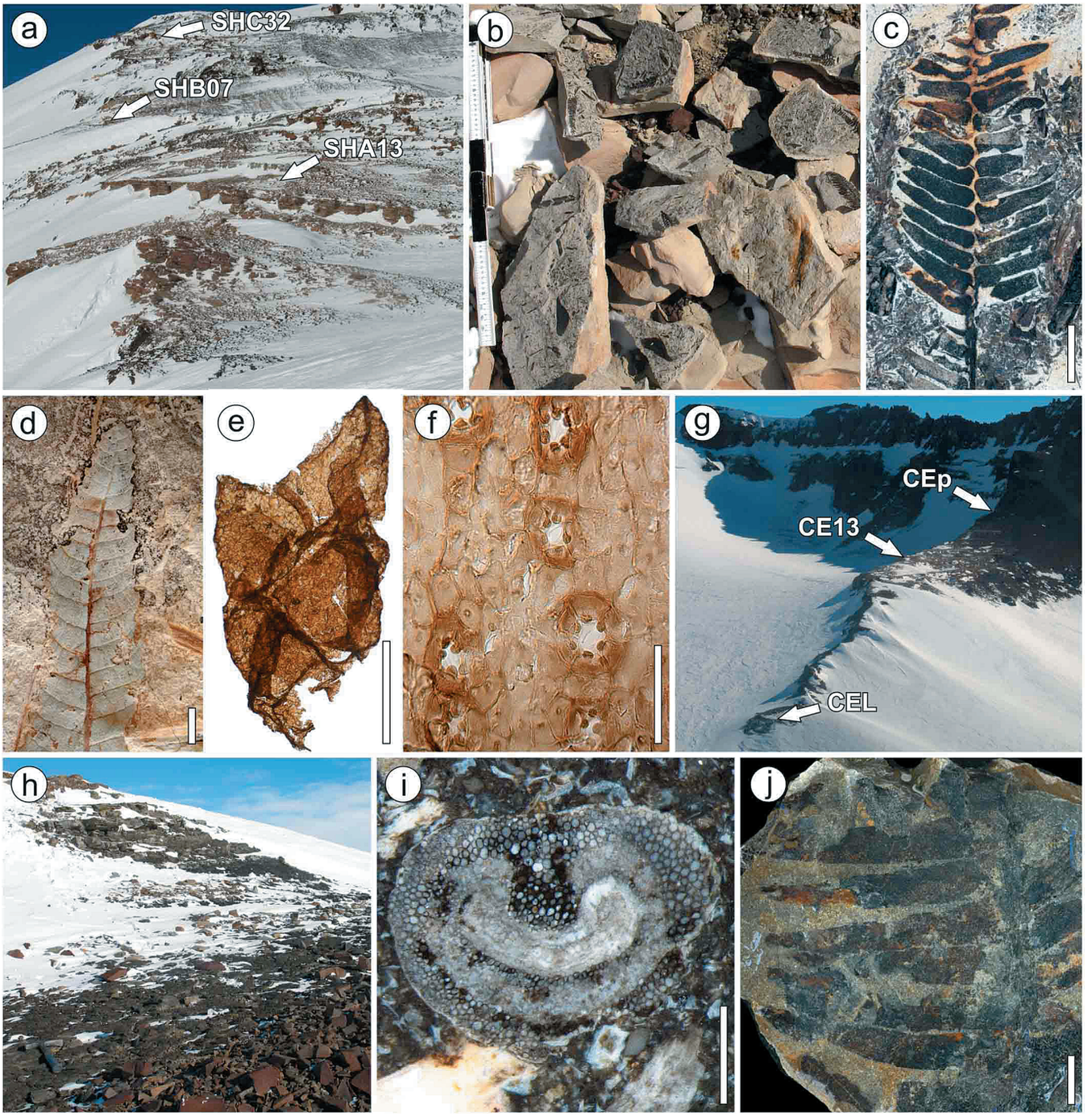

Fig. 5: Jurassic fossil sites at Shafer Peak and Mount Carson, southern north Victoria Land. (a) = overview of the sedimentary succession exposed along the northern flank of Shafer Peak, Deep Freeze Range, indicating the positions of fossiliferous horizons. (b) = Plant-bearing tuffaceous siltstones of the Jurassic Shafer Peak Formation at Shafer Peak. (c) = *Otozamites,* Shafer Peak, Lower Jurassic. Scale bar: 1cm. (d) = segment of a dipterid fern frond, Shafer Peak, Lower Jurassic. Scale bar: 1 cm. (e) = cuticle of a conifer twig retrieved from bulk macerations of samples from bed SHC32, Shafer Peak, Lower Jurassic. Scale bar: 1 mm. (f) = detail of a conifer cuticle from bed SHC32 showing cell arrangement and distribution of stomata, Shafer Peak, Lower Jurassic. Scale bar: 100 μm. (g) = overview of the sedimentary succession exposed along the eastern ridge of Mount Carson indicating the positions of fossiliferous horizons. (h) = isolated exposure of fossiliferous lake deposits at the base of the eastern ridge of Mount Carson. (i) = transverse section of a structurally preserved fern petiole or rachis from bed CEL11, Mount Carson, Lower Jurassic. Scale bar: 500 μm. (j) = segment of a large bennettitalean frond (?*Zamites*) from bed CEp, Mount Carson, Lower Jurassic. Scale bar: 1 cm.

Abb. 5: Jurassische Fossilfundstellen am Shafer Peak und Mount Carson, südliches Nordviktorialand. (a) = Überblick über die Sedimentabfolge an der Nordflanke des Shafer Peak, Deep Freeze Range, mit den Positionen fossilführender Horizonte. (b) = pflanzenführende tuffitische Siltsteine (SHC32) der jurassischen Shafer Peak Formation am Shafer Peak. (c) = *Otozamites,* Shafer Peak, Unterjura. Maßstab: 1 cm. (d) = Wedelsegment eines dipteriden Farns, Shafer Peak, Unterjura. Maßstab: 1 cm. (e) = Kutikula eines Koniferenzweigs aus Horizont SHC32, Shafer Peak, Unterjura. Maßstab: 1 mm. (f) = Detail einer Koniferenkutikula aus Horizont SHC32 mit Zellmuster und Spaltöffnungen, Shafer Peak, Unterjura. Maßstab: 100 μm. (g) = Überblick über die Sedimentabfolge am Ostrücken des Mount Carson mit den Positionen Fossil führender Horizonte. (h) = Isolierter Aufschluss fossilreicher Seeablagerungen an der Basis der Abfolge am Ostrücken des Mount Carson. (i) = Querschnitt durch eine unbestimmte Farnachse in hervorragender Zellerhaltung aus Horizont CEL11, Mount Carson, Unterjura. Maßstab: 500 μm. (j) = Teil eines großen Bennettiteenwedels (?*Zamites*) aus Horizont CEp, Mount Carson, Unterjura. Maßstab: 1 cm.

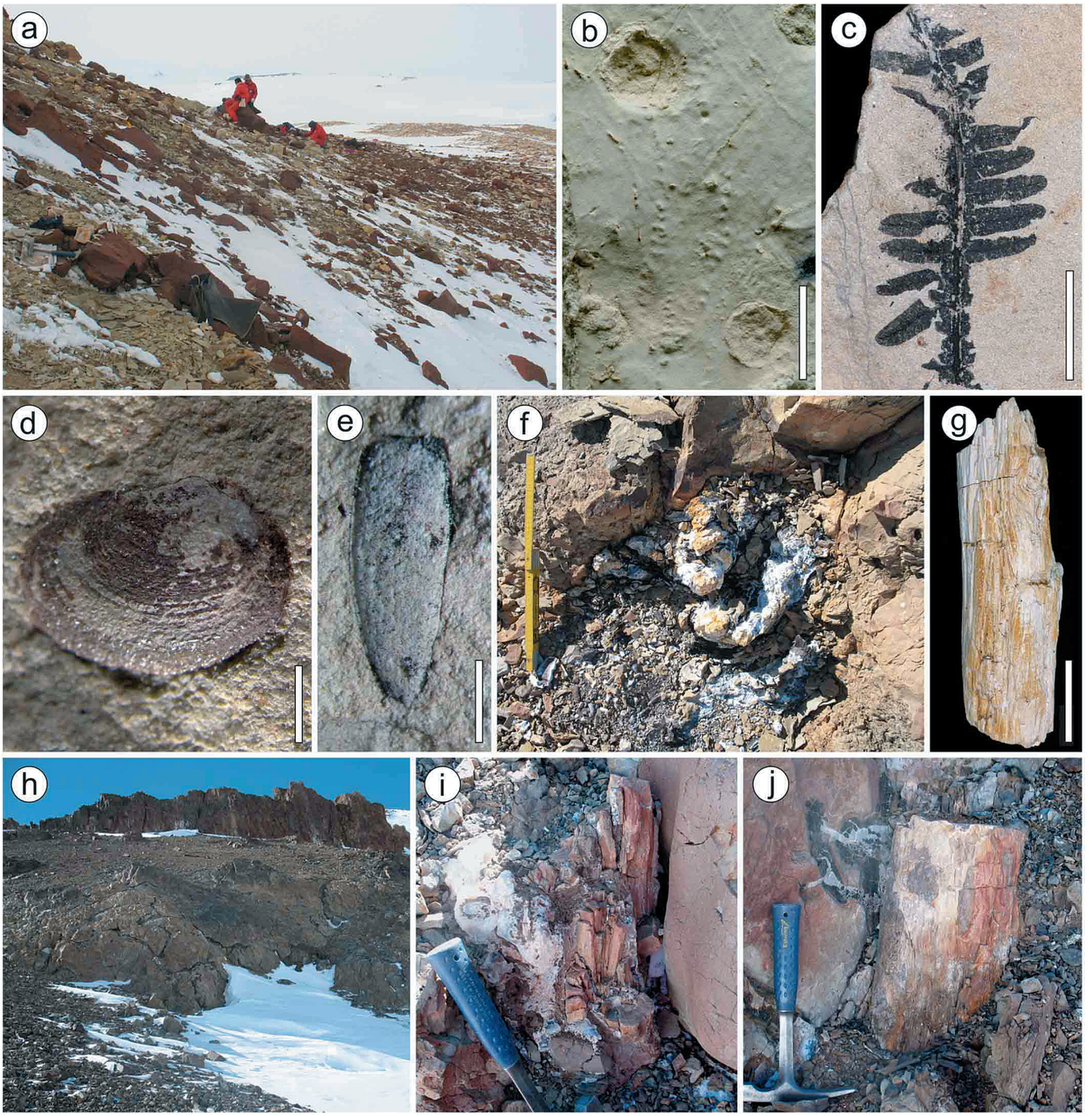

Fig. 6: Jurassic fossil sites at Mount Carson, southern north Victoria Land. (a) = Exposure of the Early Jurassic Shafer Peak Formation at the northern ridge of Mount Carson. (b) arthropod track *Diplichnites* and *Scoyenia*-type burrows from bed CN04, Mount Carson, Lower Jurassic. Scale bar: 1 cm. (c) = fern pinna, Mount Carson, Lower Jurassic. Scale bar: 1 cm. (d) = conchostracan, Mount Carson, Lower Jurassic. Scale bar: 1 mm. (e) = beetle elytron, Mount Carson, Lower Jurassic. Scale bar: 2 mm. (f) = remains of an in situ tree trunk at the southwestern spur of Mount Carson, Lower Jurassic. (g) = piece of silicified wood from the southwestern spur of Mount Carson, Lower Jurassic. Scale bar: 5 cm. (h) = base of the Kirkpatrick Lavas at Suture Bench. (i, j) = exposed parts of upright tree stems engulfed by lava flows at Suture Bench, Lower Jurassic.

Abb. 6: Jurassische Fossilfundstellen am Mount Carson, südliches Nordviktorialand. (a) = Aufschluss der frühjurassischen Shafer Peak Formation am Nordrücken des Mount Carson. (b) Arthropodenfährte *Diplichnites* und *Scoyenia*-artige Grabgänge, Mount Carson, Unterjura. Maßstab: 1 cm. (c) = Fragment eines Farnwedels; Mount Carson, Unterjura. Maßstab: 1 cm. (d) = Conchostrake, Mount Carson, Unterjura. Maßstab: 1 mm. (e) = Flügeldecke eines Käfers, Mount Carson, Unterjura. Maßstab: 2 mm. (f) = Reste eines aufrecht stehenden verkieselten Baumstammes auf dem südwestlichen Rücken des Mount Carson, Unterjura. (g) = Verkieseltes Holz, Mount Carson, Unterjura. Maßstab: 5 cm. (h) = Basis der Kirkpatrick Laven an der Suture Bench. (i, j) = aufrecht stehende Baumstämme in den Lavaströmen an der Suture Bench, Unterjura.

SW Gair Mesa (73° 32'S, 162° 45'E), Kirkpatrick lavas

A highly fossiliferous sedimentary interbed occurs between the two basal lava flows exposed at the south-western end of Gair Mesa opposite to Exposure Hill (Fig. 7a). The succession was mentioned by ELLIOT et al. (1986).

The section consists of volcaniclastic breccias, followed by lapilli-bearing volcaniclastic reddish-brown sandstones with intercalated cm-thick beds of whitish, fine-grained sand- and siltstone. Bedding planes of the fine-grained sediments display ripple marks and vertical and sub-horizontal *Scoyenia*-type burrows (Fig. 7c). The volcaniclastic rocks are overlain by a c. 15 m thick lava flow. A fluvio-lacustrine sedimentary interbed, at least 1.6 m thick, lies directly on top of the slightly irregular surface of this lava flow (Fig. 7b). The upper 40 cm of this interbed are composed of laminated lacustrine pelites that are highly fossiliferous. Numerous 5-7 mm large conchostracans (Fig. 7d, 7e, 7f), abundant ostracods and more or less fragmented, small bennettitalean fronds cover the bedding planes. In addition, a complete blattid insect (Fig. 7g) and several yet unidentified arthropod remains were found. A similar remarkable abundance of fossils and excellent preservation of arthropods is known from lake horizons in the top of the Carapace Sandstone in south Victoria Land (BRADSHAW 1987) and from lacustrine horizons interbedded between basalt flows in the central Transantarctic Mountains (i.e., Blizzard Peak and Storm Peak, TASCH 1987).

DISCUSSION AND CONCLUSIONS

The diverse array of newly discovered macrofossils from north Victoria Land (Tab. 1) highlights the great potential of Beacon and Ferrar rocks for palaeontological research. The most important finds are probably the first records of Triassic beetles from Antarctica (Fig. 3f) and the rich and well-preserved Jurassic macrofloras in the Shafer Peak Formation (e.g. Fig. 5c, 5d, 5e, 5f, 5j, 6c, 6g, 6i). Jurassic macrofloras are generally rare in East Antarctica (CANTRILL & HUNTER 2005). The excellent preservation of the plant material, especially the presence of cuticles (Fig. 4a, 4b), is likewise highly remark-

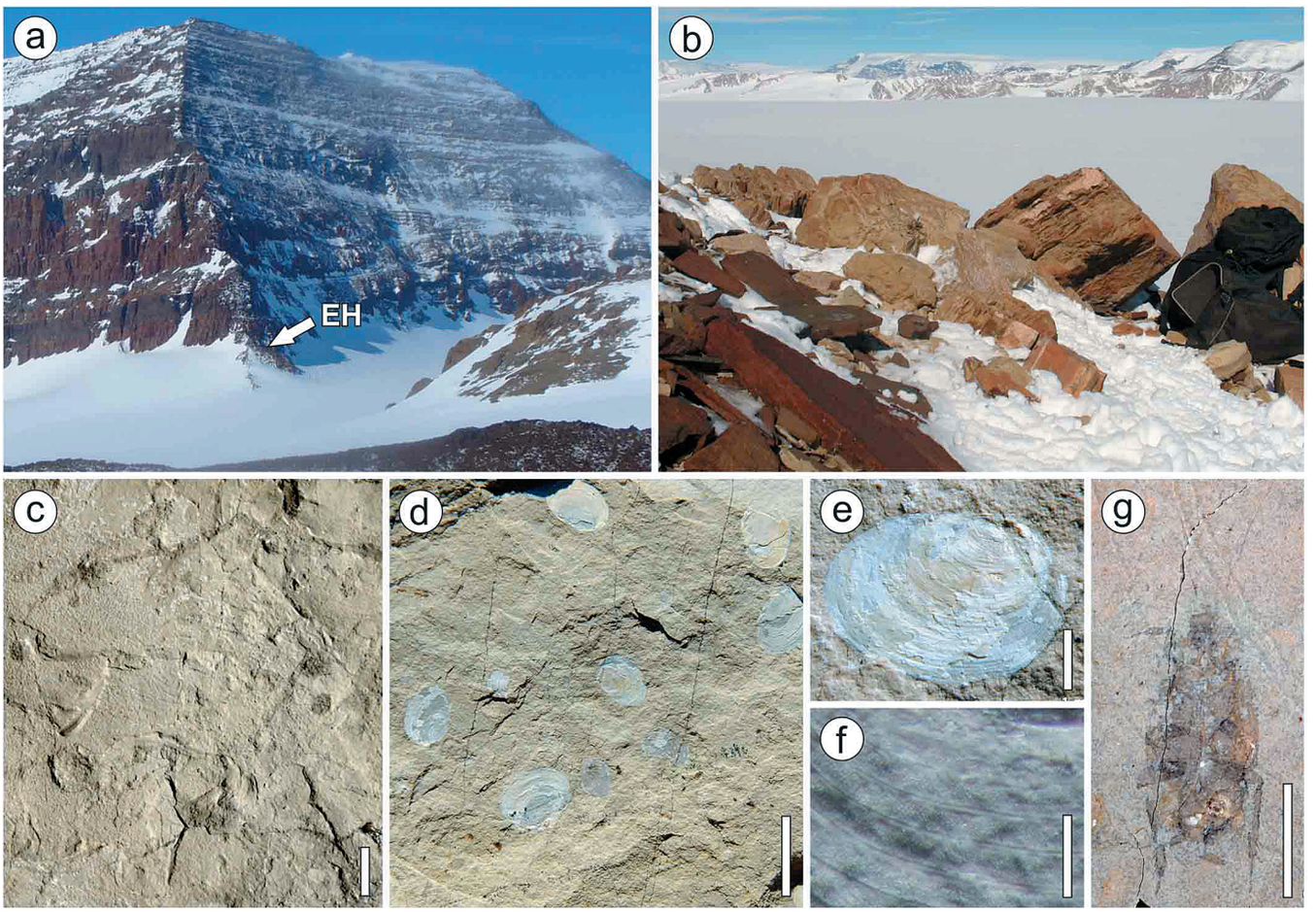

Fig. 7: Fossiliferous sedimentary interbeds between the Early Jurassic lava flows at the southwestern end of Gair Mesa, Mesa Range, southern north Victoria Land. (a) = southwestern end of Gair Mesa. Arrow indicates position of sedimentary interbeds. (b) = Large blocks of fossiliferous lake deposits with mudcracks. (c) = bedding plane with abundant *Scoyenia*-type burrows. Scale bar: 1 cm. (d) = mass occurrence of conchostracans. Scale bar: 1 cm. (e) = well-preserved conchostracan. Scale bar: 1 mm. (f) = detail of a conchostracan valve showing growth bands. Scale bar: 250 μm. (g) = an almost complete blattid insect. Scale bar: 1 cm.

Abb. 7: Fossilreiche sedimentäre Einschaltungen zwischen frühjurassischen Lavaströmen am Südwestende der Gair Mesa, Mesa Range, südliches Nordviktorialand. (a) = Südwestende der Gair Mesa. Der Pfeil markiert die Position sedimentärer Zwischenlagen. (b) = Große Blöcke fossilreicher Seeablagerungen, z.T. mit Trockenrissen. (c) = Schichtfläche mit zahlreichen *Scoyenia*-artigen Grabgängen. Maßstab: 1 cm. (d) = Massenvorkommen von Conchostraken. Maßstab: 1 cm. (e) = gut erhaltener Conchostrake. Maßstab: 1 mm. (f) = Detail einer Conchostrakenschale mit Zuwachsstreifen. Maßstab. 250 μm. (g) = ein fast vollständig erhaltenes schabenartiges Insekt. Maßstab: 1 cm.

able. The general paucity of cuticles in the Transantarctic Mountains has previously been explained as a result of intense thermal overprinting during magmatic activity of the Ferrar Large Igneous Province (TAYLOR & TAYLOR 1990). Our observations on cuticle-bearing Triassic and Jurassic plant fossil assemblages in north Victoria Land indicate that thermal influence is significant only within close proximity of the intrusive and effusive Ferrar magmas. Maturity data on the organic matter indicate that the thermal influence of thick sill intrusions declines rapidly within the first metres to tens of metres away from the sill (BERNER et al. 2009). Cuticles represent a very helpful tool for taxonomic studies and also enable detailed palaeoecological and paleoclimatological interpretations of plant fossils (KERP 1990). The frequent occurrence of anatomical preservation is most likely related to a large supply of permineralizing agents in the volcanically influenced environment. Of particular interest is the anatomically preserved Early Jurassic flora from Mount Carson (Fig. 5i). Although there are many examples of permineralized Permian and Triassic floras from the Antarctic (see TAYLOR & TAYLOR 1990), anatomically preserved Jurassic plants are extremely rare (YAO et al. 1991). Noteworthy are the upright buried tree trunks at Suture Bench (Fig. 6i, 6j) and the spur southwest of Mount Carson (Fig. 6f). Similar occurrences of in situ tree stands in lava flows have been reported from the Mesa Range (JEFFERSON et al. 1983). The abundance of isolated rafts of Triassic permineralized peat substantiates that such deposits containing structurally preserved plants are much more widespread in the Transantarctic Mountains than previously recognized (TAYLOR & TAYLOR 1990).

Although work is still in progress, the palaeontological data obtained so far are instrumental in clarifying the age of the sedimentary sequence in north Victoria Land. The beginning of the sedimentation is still very difficult to define because macrofossils are lacking, and palynological samples have thus far turned out barren. The associations of *Dicroidium, Heidiphyllum,* and *Linguifolium* at Timber Peak (Fig. 3g, 3h) and Vulcan Hills (Fig. 4d, 4e, 4f, 4g) confirm a Triassic age for the middle part of the Section Peak Formation. The upper part of the Section Peak Formation is Early Jurassic in age as indicated by microfloras from Section Peak (NORRIS 1965, PERTUSATI et al. 2006). The Triassic-Jurassic boundary is thus supposed to lie within the alternation of sandstone sheets and fine-grained sediments exposed in the cliff faces of the Deep Freeze Range, e.g., at the Priestley Glacier. As a consequence, the coal-bearing fine-grained intercalations above the *Dicroidium*-floras were probably deposited synchronously with the coarse-grained channel sandstone facies at Section Peak. The age of the Shafer Peak Formation is Early Jurassic because it is bracketed between the underlying earliest Jurassic sandstones and the radiometrically dated late Early Jurassic Kirkpatrick lava flows (183.6 ±2.1 Ma, ENCARNACIÓN et al. 1996). The new macrofloras are well in accordance with this age estimate. These floras are characterized by a dominance of cycadophyte fronds (Fig. 5c, 5j), especially *Otozamites,* along with a variety of fern foliage and sparse conifer remains, whereas other typical Triassic elements such as *Dicroidium, Heidiphyllum* or *Linguifolium* are absent.

Palynological analyses are currently being conducted. A detailed biostratigraphic framework will help to more precisely define the onsets of sedimentation and silicic and mafic volcanic activity in north Victoria Land. We are confident that this will ultimately contribute to a more accurate understanding of the timing and evolution of the Ferrar Large Igneous Province, and of the vast environmental changes that the Antarctic ecosystems experienced during this interesting period of Earth history.

ACKNOWLEDGMENTS

We thank the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover, for the invitation to join GANOVEX IX, for generous logistical support and, above all, for a great time in the field. Further technical support by the Alfred-Wegener-Institut (AWI), Bremerhaven, is gratefully acknowledged. We thank Christian Pott (Stockholm) and Michael Krings (München) for valuable comments and suggestions that have greatly helped to improve this manuscript. This research project was funded by the Deutsche Forschungsgemeinschaft (DFG), grants VI 215/6-1, SCHN 408/11-1, KE 584/12, KE 584/16-1 and GA 457/11-1.

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